PURPOSE

CONCEPTS FOR STUDY OF THE CONTAMINATION POTENTIAL OF BEDROCK AQUIFERS IN THE BLACK HILLS AREA, WESTERN SOUTH DAKOTA

The following document presents general concepts for studies of the contamination potential of bedrock aquifers in the Black Hills area of western South Dakota. One of our objectives in posting this document on this web page is to provide an example of how pharmaceuticals and personal care products (PPCPs) might be used as tools for helping to solve an environmental problem. PPCPs are one of several tracers that might be used effectively to evaluate ground-water mixing conditions and travel times in the complex hydrogeologic setting of the Black Hills area. Another purpose is to solicit interest from other researchers who might envision opportunities for collaborative studies. Input regarding concepts presented in this paper are invited and may be directed to:

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CONCEPTS FOR STUDY OF THE CONTAMINATION POTENTIAL OF BEDROCK AQUIFERS IN THE BLACK HILLS AREA, WESTERN SOUTH DAKOTA

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PROBLEM

Bedrock aquifers are the primary source of drinking water in the Black Hills area of western South Dakota. Large secondary porosity and permeability from fracturing or solution enhancement can allow extremely rapid infiltration of recharge with very little filtering of potential contaminants. Extensive development that is occurring in recharge areas has potential for introduction of contaminants. Contamination of bedrock aquifers could impair the quality of water supplies for a large part of the population in the Black Hills or require investment in expensive water treatment facilities. Conversely, limiting growth and development in recharge areas also has substantial economic implications. Thus, studies are needed to evaluate the potential for contamination of bedrock aquifers in the Black Hills area.

BACKGROUND INFORMATION

The hydrogeology of the Black Hills area is extremely complex. The central core of the Black Hills is comprised primarily of Precambrian crystalline (metamorphic and igneous) rocks, from which an overlying sequence of sedimentary rock units has been eroded. The sedimentary rocks generally were deposited in nearly horizontal beds. Subsequent uplift during the Laramide orogeny and related erosion exposed the Precambrian rocks in the crystalline core of the Black Hills, with outcrops of the sedimentary units exposed in roughly concentric rings surrounding the core (fig. 1).

The hydrogeologic setting of the Black Hills area is schematically illustrated in figure 2. Many of the sedimentary bedrock units contain aquifers, including the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers (from oldest to youngest), which are utilized extensively within the Black Hills area. The Precambrian rocks, which generally have relatively low permeability, comprise a confining unit beneath the sedimentary sequence. Numerous localized aquifers occur within fractured and weathered zones in the crystalline core area, however. All of the aquifers receive recharge from infiltration of precipitation on outcrop areas, and the Madison and Minnelusa aquifers receive substantial recharge from large streamflow losses that occur in loss zones where stream channels cross outcrop areas. The Minnekahta aquifer also may receive some recharge from streamflow losses.

Large secondary porosity and permeability resulting from fracturing or solution enhancement are common in the bedrock aquifers, especially within the Madison, Minnelusa, and Minnekahta aquifers. These features can result in high well yields in many locations, but also can allow extremely rapid infiltration of recharge with very little filtering of potential contaminants. These features also can allow rapid lateral movement of ground water, which creates potential for rapid transport of contaminants. In addition, highly heterogeneous (non-uniform) aquifer conditions can result in highly variable ground-water flow and mixing conditions.

Bedrock aquifers that are recharged in the Black Hills area are used extensively for water supplies in the area. Population growth in the area is resulting in increased demand for water supplies and increased potential for contamination of bedrock aquifers. Thus, information regarding the contamination potential of bedrock aquifers in the Black Hills area would be extremely useful for a variety of water-resource managers and land-use planners.

OVERVIEW OF POTENTIAL STUDY

A study to evaluate the potential for contamination of bedrock aquifers would require sampling numerous locations in various aquifers for a number of constituents indicative of human (anthropogenic) influence. A primary source of anthropogenic influence probably is individual onsite waste-disposal systems (septic systems). Other potential sources of contaminants may include chemicals applied to lawns, automotive byproducts contained in runoff from roads, and catastrophic spills or releases of petroleum products or industrial chemicals.

Extensive knowledge of ground-water flow and mixing conditions in bedrock aquifers also would be necessary to evaluate the potential for contamination. Investigations by Naus and others (2001) indicated a wide variety of ground-water traveltimes and mixing conditions in the Madison and Minnelusa aquifers. Many wells considered contained small (or negligible) proportions of water recharged since about 1950. Furthermore, proportions of recharge influenced by anthropogenic activities generally would be small, relative to total recharge. Thus, constituents indicative of anthropogenic influence currently would be extremely diluted in ground water in many locations.

Proportions of recharge influenced by anthropogenic activities presumably will increase as population growth continues. Increasing anthropogenic activities, in combination with ongoing displacement of relatively old ground water by younger water, eventually will increase concentrations of constituents indicative of anthropogenic influence in some locations. Thus, detection of extremely dilute concentrations of various constituents in ground water could provide early indications of potential water-quality problems in the future.

Purpose and Scope

The purpose of the proposed study would be to evaluate the potential for contamination of bedrock aquifers in the Black Hills area. As discussed, obtaining additional information regarding ground-water flow and mixing conditions would be necessary for evaluation of contamination potential. General objectives of the study might include:

(1) Assessing ground-water flow and mixing conditions in selected bedrock aquifers;

(2) Investigating the occurrence of early indicators of anthropogenic influence in ground water;

(3) Using information derived from objectives 1 and 2 to evaluate the general potential for contamination of bedrock aquifers; and

(4) Establishing a long-term monitoring network for water-quality indicators.

The study area for the proposed study probably would be similar to that used for the Black Hills Hydrology Study, which includes most of the major population centers in the Black Hills area. The highest priority probably would be placed on the Madison and Minnelusa aquifers, which are extensively utilized for water supplies and have especially large secondary porosity and permeability. Relatively high priorities also could be placed on the Minnekahta aquifer and on localized aquifers in the crystalline core area. The Minnekahta aquifer, which has relatively large secondary porosity and permeability, is utilized extensively for domestic water supplies and has been subject to extensive development during recent years in many outcrop areas. In addition, the Minnekahta aquifer may have relatively large influence from anthropogenic activities because of limited thickness, which results in small storage capacity relative to the Madison and Minnelusa aquifers. Similarly, localized aquifers in the crystalline core area can have large secondary porosity and permeability, relatively small saturated thickness, and are subject to extensive development and utilization in some outcrop areas. Indications of anthropogenic influence in the Minnekahta aquifer and localized aquifers in the crystalline core area could provide important insights regarding the potential for contamination of other bedrock aquifers in the Black Hills area. The lowest priority probably would be placed on the Deadwood and Inyan Kara aquifers, which probably have larger capacity for filtering of potential contaminants because secondary porosity and permeability generally are smaller than in the other aquifers.

Approach and Methods

A variety of approaches and methods would be needed to evaluate the potential for contamination of bedrock aquifers in the Black Hills area. As discussed, extensive knowledge of ground-water flow and mixing conditions in bedrock aquifers would be prerequisite to initiation of a sampling program designed to detect indicators of anthropogenic influence. This knowledge would be required because: (1) substantial variability exists in ground-water traveltimes from recharge areas to potential sampling locations; (2) at any potential sampling location, the proportion of ground water currently in storage that has been influenced by anthropogenic activities may be small, but probably is subject to increase over time. Thus, sampling efforts for the proposed study would be divided into two categories, including sampling to obtain knowledge of ground-water flow and mixing conditions, and sampling to provide early indications of anthropogenic influence. The potential need for long-term monitoring for indicators of anthropogenic influence at selected locations could be evaluated at a later date.

An array of environmental tracers would be used in evaluating the potential for contamination of bedrock aquifers in the Black Hills area. Two general categories of environmental tracers that would be considered include "recharge tracers" that would be used in assessing ground-water flow and mixing conditions and "anthropogenic indicators" that would be used as indicators of anthropogenic influence. Anthropogenic indicators also could be useful in evaluating ground-water flow and mixing conditions. Details regarding the use of various tracers in evaluating ground-water flow conditions in bedrock aquifers and potential for contamination are described in the following sections.

Recharge Tracers

Recharge tracers would include a variety of tracers introduced into ground water independently of localized anthropogenic activities. These tracers generally are introduced at the time of recharge and generally are not influenced by rock/water interactions within an aquifer. Unique chemical signatures can be imparted to water molecules, or dissolved gases within water, which can be measured with a high degree of accuracy and can be used to obtain insights regarding recharge areas, time of recharge, or mixing conditions within an aquifer. Various complications and limitations can exist regarding interpretation of results for any individual tracer; however, consideration of a suite of different recharge tracers can provide multiple lines of evidence that are useful in interpreting results.

Detection of anthropogenic indicators in ground water would require identification of sampling locations where anthropogenic influences in contributing recharge areas are large enough, and recent enough, to result in measurable concentrations. Thus, one purpose of sampling for recharge tracers would be to identify locations with relatively large proportions of recently recharged water, where detection of anthropogenic indicators would be likely (assuming sufficient anthropogenic influence within likely recharge areas). Another important purpose would be to improve capabilities for assessing ground-water flow and mixing conditions, which would require sampling for recharge tracers in numerous locations, regardless of current potential for anthropogenic influence. Accomplishing this purpose also would require some sampling of recharge water and might include sampling of both streamflow in loss zones and precipitation.

Although many locations sampled for recharge tracers probably would not be sampled immediately for anthropogenic indicators, background information obtained could be useful for a variety of future purposes such as identifying source water protection areas for community water supplies. Information obtained also would contribute to a better understanding of general hydraulic and ground-water flow characteristics for bedrock aquifers in the Black Hills area, which would have increasing utility as demand for available water supplies increases.

Preliminary information regarding complex ground-water flow and mixing conditions for the Madison and Minnelusa aquifers has been obtained from the Black Hills Hydrology Study. Naus and others (2001) described simplified conceptual mixing models that could have general applicability for various hydrogeologic conditions in the Black Hills area (fig. 3). These investigators concluded that slug-flow conditions (fig. 3A) probably are uncommon in the Madison and Minnelusa aquifers. The other two mixing models are based on simplifying assumptions of equal annual recharge and thorough mixing conditions. Although actual conditions routinely violate these assumptions, the mixing models provide a general starting point for assessing ground-water flow and mixing conditions in outcrop areas (fig. 3B) and areas where artesian conditions occur (fig. 3C).

Naus and others (2001) identified non-uniform mixing conditions as a particularly problematic complicator for analysis of ground-water traveltimes. An explicit example was provided for several wells in northwestern Rapid City that are downgradient from the streamflow loss zone in Boxelder Creek. Results of previous dye testing, in combination with age dating based on tritium concentrations (a recharge tracer described later), indicated extremely non-uniform mixing conditions. For several sites, dye recovery indicated arrival times of less than 50 days for some water recharged in the Boxelder Creek loss zone; however, tritium concentrations also indicated substantial proportions of water that was recharged at least 50 years previously, with a general absence of intermediate-aged water.

Ongoing studies to address site-specific considerations in the Rapid City and Spearfish/Lawrence County areas are providing additional information regarding the use of various recharge tracers for analysis of ground-water flow and mixing conditions. Much additional information is needed, however, to develop viable methods for assessing ground-water flow conditions for bedrock aquifers throughout the Black Hills area. Most of the information currently available has been collected from the Madison and Minnelusa aquifers; information regarding other bedrock aquifers is sparse or nonexistent. Repetitive sampling for recharge tracers (at intervals of about 3 to 5 years) in some locations would be useful to address transient ground-water flow conditions that can result from changing recharge conditions and from steadily increasing withdrawals from bedrock aquifers.

Following is an overview of recharge tracers that may be useful for analysis of ground-water flow and mixing conditions in bedrock aquifers in the Black Hills area. Brief discussions of background information, capabilities, and limitations are provided.

Stable Isotopes of Oxygen and Hydrogen

The stable isotopes of oxygen (^{18}O and ^{16}O) and hydrogen (^{2}H, dueterium; and ^{1}H) are useful primarily for evaluating ground-water flowpaths and recharge areas. Ratios between heavy and light isotopes are reported in delta notation expressing differences, in parts per thousand (per mil) from reference standards. Dueterium/hydrogen (δD) ratios correlate directly with $^{18}O/^{16}O$ ($\delta^{18}O$) ratios; thus, following discussions refer only to $\delta^{18}O$ values for simplicity. Distinctive $\delta^{18}O$ signatures in the Black Hills area (fig. 4) result from orographic effects and differences in storm patterns (Naus and others, 2001), with isotopically lighter (more negative) values occurring in higher altitudes and latitudes. In some cases, these signatures can be used to evaluate recharge areas or characteristics, such as dominance by streamflow recharge, which commonly is isotopically lighter than infiltration of precipitation on outcrop areas that occur at relatively lower altitudes. Temporal changes in $\delta^{18}O$ values in precipitation generally are relatively small; however, minor $\delta^{18}O$ trends in ground water (at locations where sufficient data are available) can provide indications of mixing conditions within an aquifer.

Precise identification of recharge areas for individual sampling locations generally is not possible. Large recharge occurring in discrete streamflow loss zones can disperse throughout large areas in an aquifer, mixing with additional recharge from infiltration of precipitation over large outcrop areas. Large discharges of large springs and large production wells generally necessitate large recharge areas, relative to springs or wells with small discharge. Ground-water flowpaths are subject to changes resulting from transient recharge conditions and changing spring and well discharges. In spite of numerous complications, $\delta^{18}O$ values have demonstrated utility for estimating recharge areas and additional sampling would be beneficial. Sampling for anthropogenic indicators also may be useful in helping to estimate recharge areas in some locations.

Tritum

The radioisotope tritium (^3H), which beta-decays to ^3He with a half-life of 12.43 years (Clark and Fritz, 1997), is produced naturally in small concentrations by cosmic radiation in the stratosphere. Because of nuclear testing during the 1950’s and 1960’s and a subsequent treaty limiting such tests, tritium concentrations in atmospheric water increased sharply in 1953, peaked in 1963, and then declined. Estimated concentrations by Naus and others (2001) for precipitation in the Black Hills area are shown in figure 5, along with decay curves for selected 12-year increments that approximate the half-life decay of tritium.

Despite various limitations described by Naus and others (2001), tritium can be very useful for evaluating ground-water traveltimes and mixing conditions (relative proportions of water recharged during different timeframes). Tritium concentrations in current samples exceeding 1.0 tritium units generally provide a positive indication of some water recharged since about 1953 (fig. 5) and concentrations less than about 10 tritium units indicate some proportion of recharge prior to 1953. Multiple samples (over time) for any location generally improve capabilities for narrowing potential age ranges. Similarly, collection of simultaneous samples for other age-dating parameters also improves age-dating capabilities.

Tritium/Helium

This method compares concentrations of tritium and the noble gas helium, which is the decay product of tritium. Samples with large proportions of water recharged during the 1950’s, 60’s, and 70’s generally should have relatively large concentrations of helium resulting from decay of relatively large quantities of tritium (fig. 5). Many samples previously collected in the Black Hills area have tritium concentrations in the range of about 10 to 40 tritium units (Naus and others, 2001), which could be representative of a broad range of potential recharge ages and mixing conditions. This method could be particularly useful in assessing recharge ages and mixing conditions for many samples with tritium concentrations in this range. Some preliminary sampling would be required to determine background concentrations of helium. High background concentrations could introduce unacceptable errors in calculation of helium originating from tritium decay.

Chlorofluorocarbons

Chlorofluorocarbons (CFC's), which are gases that originate primarily from refrigerants, increased markedly in the atmosphere in the 1960's (fig. 6) and are especially useful for characterizing relatively young ground water. Because the shapes of the CFC curves are different with respect to time, comparing all three CFC's can constrain the range of recharge ages and mixing conditions for some samples. Concentrations of CFC's in water samples generally increase with increasing proportions of relatively young water. This characteristic can be advantageous, relative to the use of tritium, which generally provides fewer constraints regarding potential recharge ages (fig. 5).

Exposure to the atmosphere can impart a modern signature to water samples; thus, special procedures are needed for collection of CFC samples and samples for other dissolved gases. In addition, CFC sampling may not provide reliable results for some potential sampling locations such as springs, where atmospheric exposure cannot necessarily be avoided. Furthermore, modern signatures may be imparted to relatively old ground water through atmospheric exposure that occurs in caverns, which are especially common in the Madison Limestone.

Sulfur Hexafluoride

Atmospheric concentrations of sulfur hexafluoride (SF_6), which is a gas originating from electrical transformers, have been increasing during the last 20 years. Thus, SF_6 has potential for characterizing relatively young ground water that has been recharged since about 1980. This method currently is in experimental stages and ongoing research is assessing possible background levels in igneous rocks. This tracer could be useful in some locations.

Anthropogenic Indicators

Anthropogenic indicators could include a variety of potential tracers indicative of localized anthropogenic activities. Improved analytical capabilities have resulted in extremely low detection limits for a variety of compounds that have potential utility as anthropogenic indicators. Although detectable concentrations of various anthropogenic indicators would not necessarily pose a current health risk, detection of dilute concentrations of various indicators in ground water could provide early indications of potential water-quality problems in the future. Following is an overview of several categories of anthropogenic indicators that may be useful in evaluating the potential for contamination of bedrock aquifers in the Black Hills area.

Low-level nutrients

Although nutrients occur naturally in the environment, concentrations of nutrients can be increased by a variety of anthropogenic activities. A list of appropriate nutrients, along with low-level reporting limits is provided in table 1. Evaluation of anthropogenic influence based on nutrient concentrations would require estimating naturally occurring background levels for the Black Hills area. An abundance of relevant information for evaluating background levels already is available (Williamson and Carter, 2001); however, some additional sampling may be needed.

Wastewater compounds

A variety of compounds frequently found in wastewater (table 2) may be useful as anthropogenic indicators. These compounds can be derived from a variety of sources, including food additives, fragrances, antioxidants, flame retardants, plasticizers, solvents, disinfectants, fecal sterols, polycyclic aromatic hydrocarbons, and high-use domestic pesticides. Minimum reporting levels range from 0.5 to 5 parts per billion, which allows detection at extremely small concentrations. Although many of the compounds included in the analytical schedule (table 2) may not be detected in samples collected in the Black Hills area, analytical costs cannot be reduced by reducing the number of compounds considered.

Pharmaceuticals and personal care products

Pharmaceuticals and personal care products (PPCP's) refer to a wide variety of substances which general originate from various medications such as antibiotics, hormones, or steroids. Many of these substances are considered to be "emerging contaminants" because very little is known about potential health risks associated with extremely small concentrations of various substances, or exposure to combinations of substances. Research in this field is just beginning to address these issues; however, concern exists that health risks may be substantial, especially regarding exposures for infants. Limited sampling for PPCP's may be justified in some locations.

As previously discussed, current concentrations of anthropogenic indicators in most potential ground-water sampling locations probably are not indicative of current anthropogenic influences because traveltimes from recharge areas delay the arrival of indicators at sampling locations and concentrations are diluted by ground-water mixing. In addition, recharge influenced by anthropogenic activities probably constitutes a relatively small proportion of total recharge in most areas. Thus, concentrations of anthropogenic indicators probably are small in most locations and sampling efforts would first need to be focused in areas with relatively high probabilities of detecting indicators. The highest probabilities generally would exist for sites (wells or springs) with high proportions of recently recharged water that are downgradient from recharge areas where extensive and long-term development has occurred.

Samples for anthropogenic indicators also should be collected from small streams in basins with extensive development pressure, which would provide an indication of whether anthropogenic indicators can be detected in a setting where traveltimes are inconsequential. Such sampling also would provide an indication of concentrations that might be expected in streamflow recharge.

Implementation of Study

Implementation of a study to evaluate the potential for contamination of bedrock aquifers in the Black Hills area could begin relatively soon. Planning required for initial implementation of preliminary study efforts may be relatively minor; however, preliminary results will need to be considered before some of the future study directions can be determined.

Initial study efforts probably would consist of: (1) sampling for anthropogenic indicators in small streams in basins with extensive development pressure, to determine whether anthropogenic indicators can be detected in this setting; and (2) sampling for various recharge tracers in a variety of settings, to evaluate the utility of various methods for assessing ground-water flow and mixing conditions. Ongoing studies to address site-specific considerations in the Rapid City and Spearfish/Lawrence County areas should provide some preliminary information; however, additional information probably will be needed to fully evaluate the capabilities of various methods.

As discussed, future study directions would be determined following consideration of preliminary results. Sampling for anthropogenic indicators in ground-water would first require identification of high-probability sites with relatively large proportions of recently recharged water and relatively large potential for anthropogenic influence. The need for subsequent sampling of progressively lower probability sites would be driven by detection of anthropogenic indicators at higher probability sites.

REFERENCES

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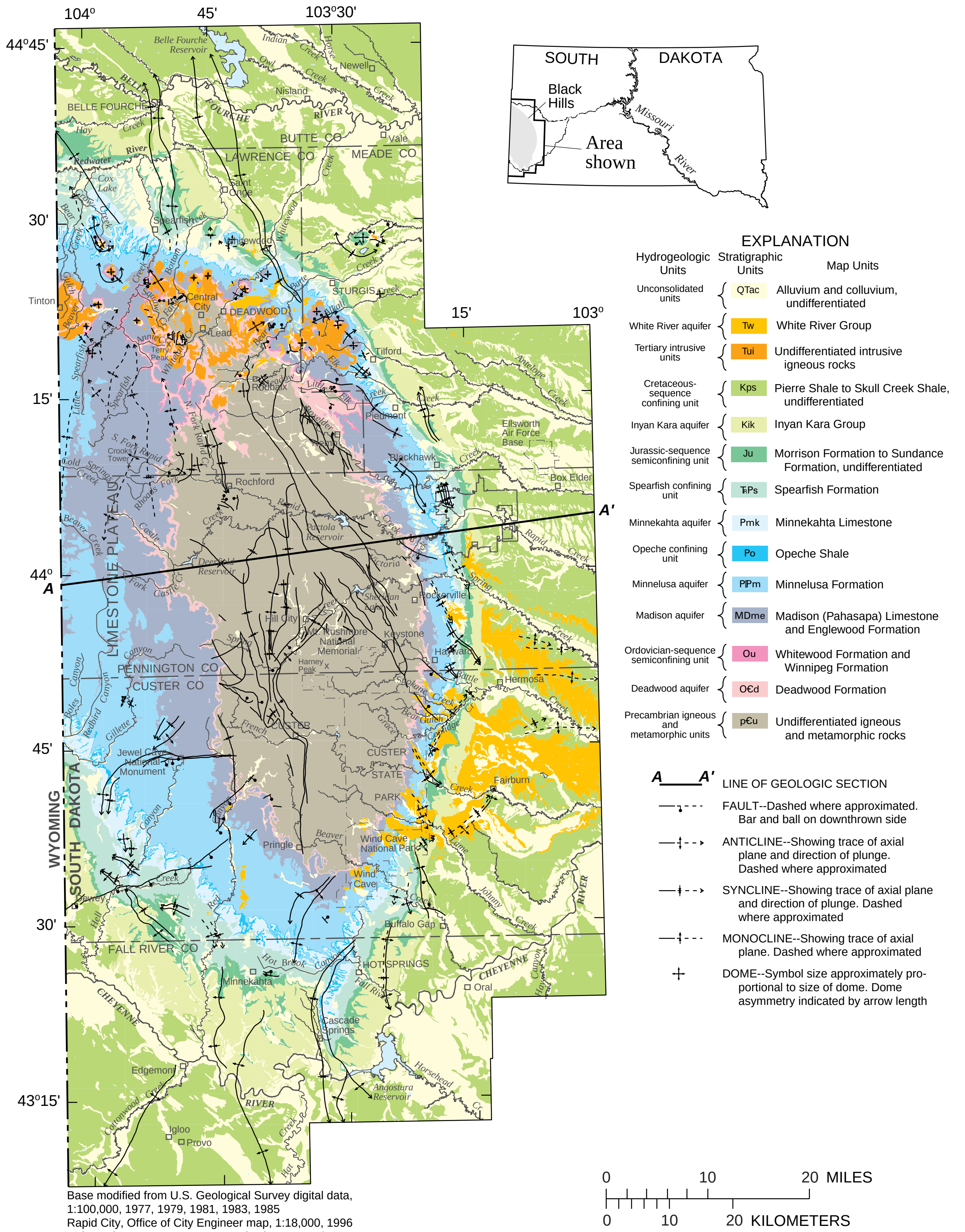
Naus, C.A., Driscoll, D.G., and Carter, J.M., 2001, Geochemistry of the Madison and Minnelusa aquifers in the Black Hills area, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 01-4129, 118 p.

Williamson, J.E., and Carter, J.M., 2001, Water-quality characterisitics in the Black Hills area, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 01-4194, 196 p.

Figures and Tables



Base modified from U.S. Geological Survey digital data, 1:100,000, 1977, 1979, 1981, 1983, 1985
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 1. Distribution of hydrogeologic units in the Black Hills area (modified from Strobel and others, 1999).

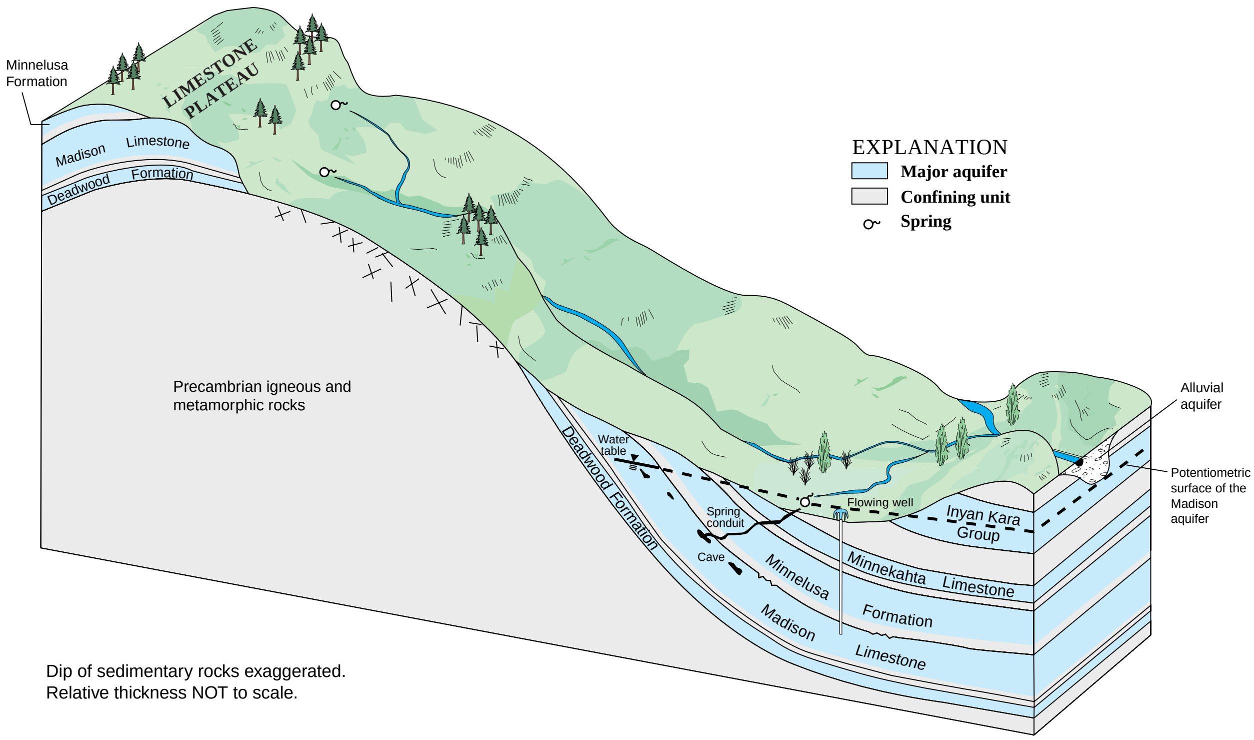
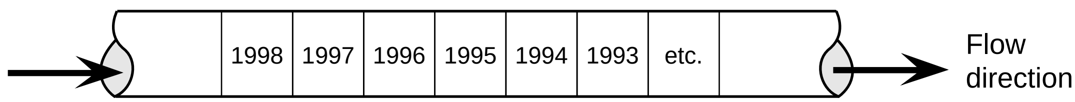
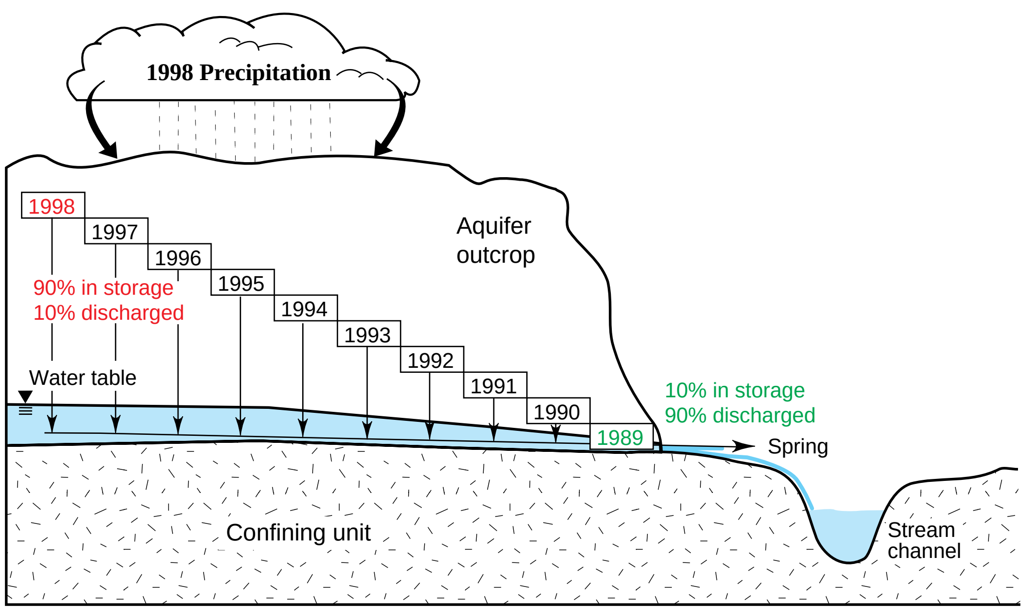


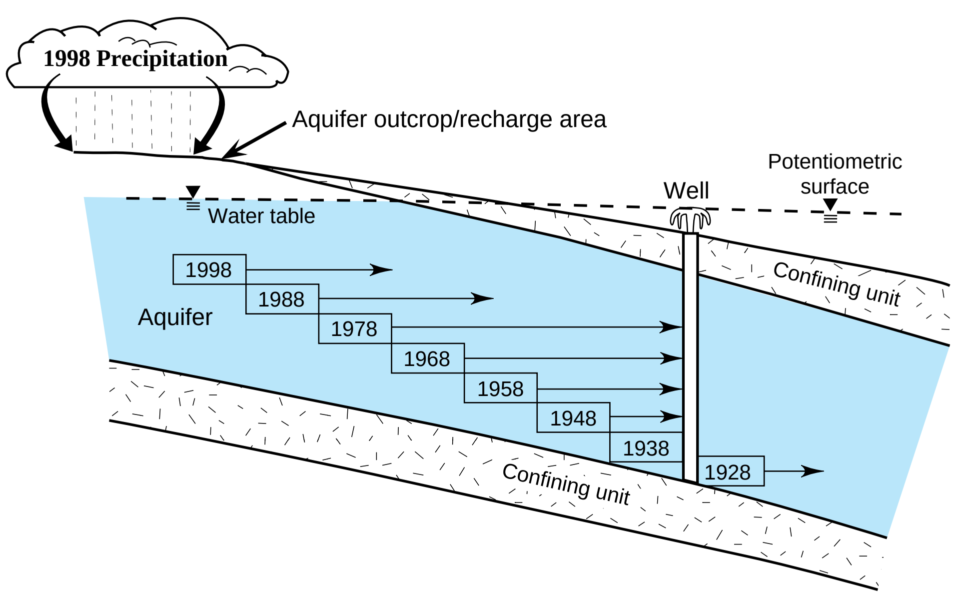
Figure 2. Schematic diagram showing simplified hydrologic setting of the Black Hills area. Schematic diagram generally corresponds with geologic cross section shown in figure 20.



A. Slug flow or pipe flow - negligible mixing with delayed arival

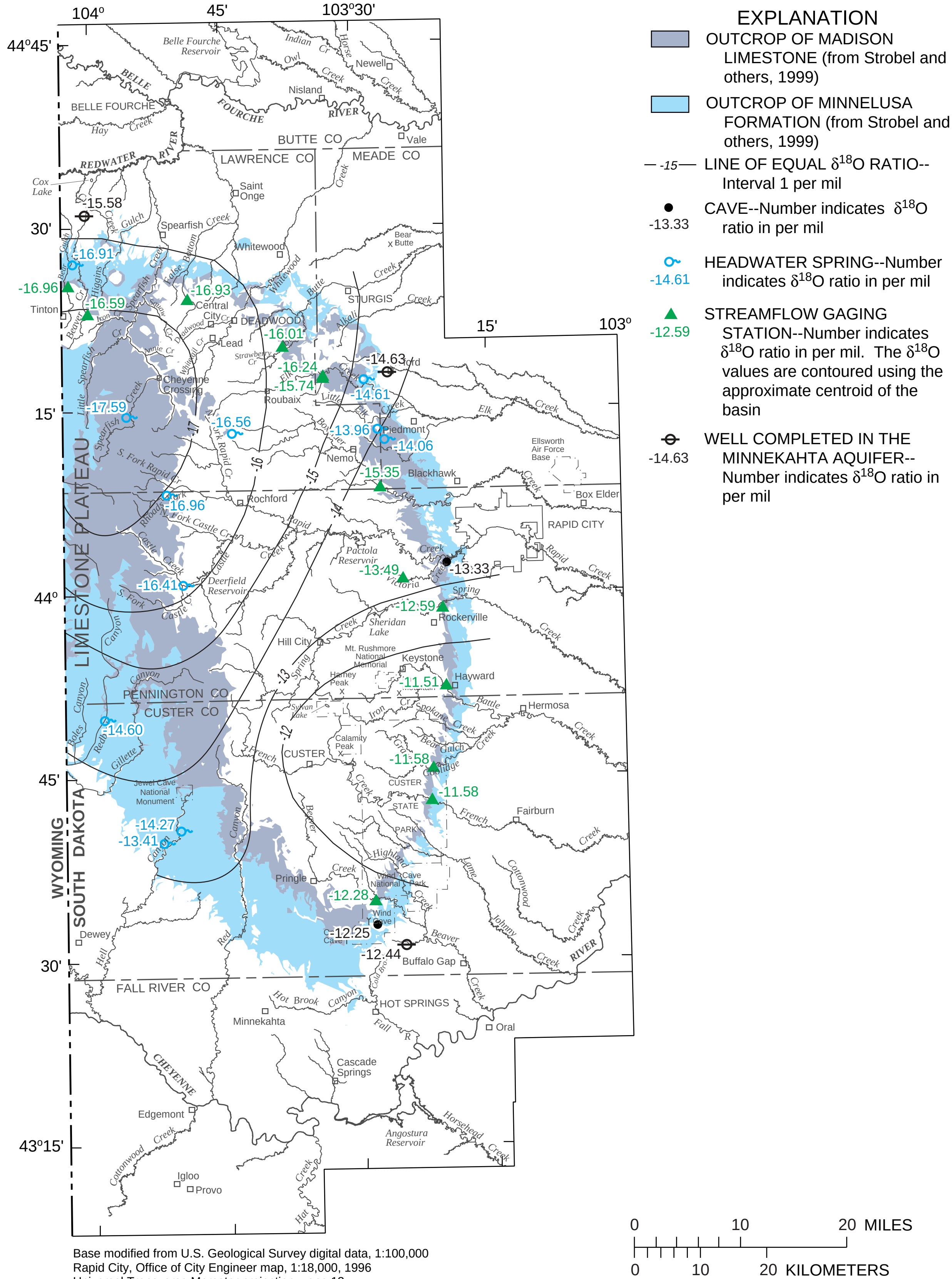


B. Hypothetical water-table spring with maximum traveltime of 10 years - thorough mixing with immediate arrival



C. Well completed in artesian aquifer at considerable distance from recharge area - thorough mixing with delayed arrival

Figure 3. Schematic diagrams illustrating mixing models for age dating for various ground-water flow conditions.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 4. Generalized distribution of $\delta^{18}O$ in surface water and ground water in near-recharge areas.

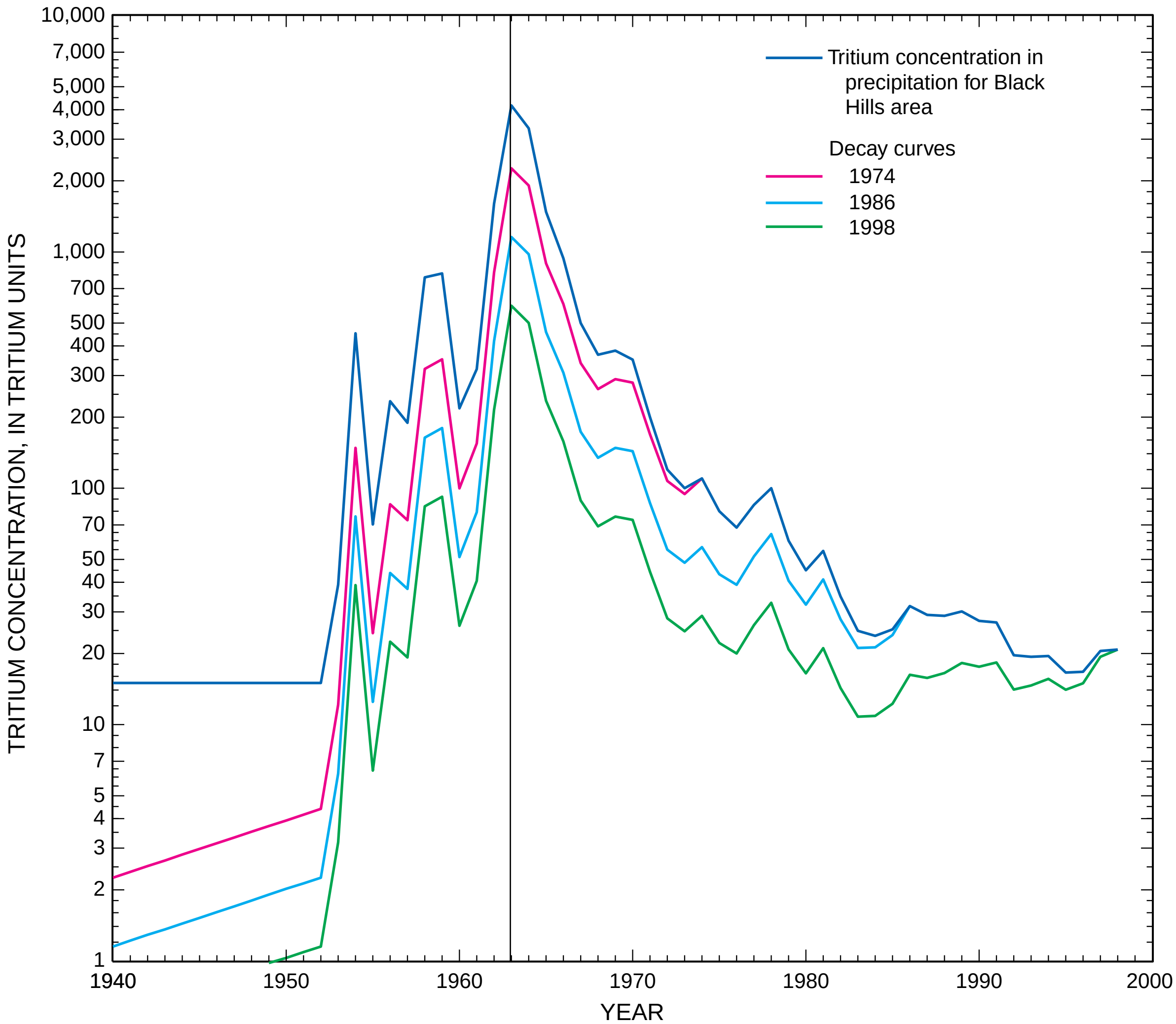


Figure 5. Estimated tritium concentrations in precipitation for Black Hills area and decay curves for selected years. Decay curves depict decayed tritium concentrations for selected sampling years. Maximum tritium concentrations of about 4,200 tritium units occurred in about 1963. Tritium has a half-life of about 12.43 years and decay curves are presented for selected 12-year increments that approximate this half life. Using 1963 as an example, the tritium concentration in a sample collected in 1974 containing water recharged in 1963 would be equal to about 2,200 tritium units. The tritium concentration would have decayed by almost one-half to 1,100 tritium units for a sample collected 12 years later in 1986, and again by one-half to about 600 tritium units for a sample collected in 1998.

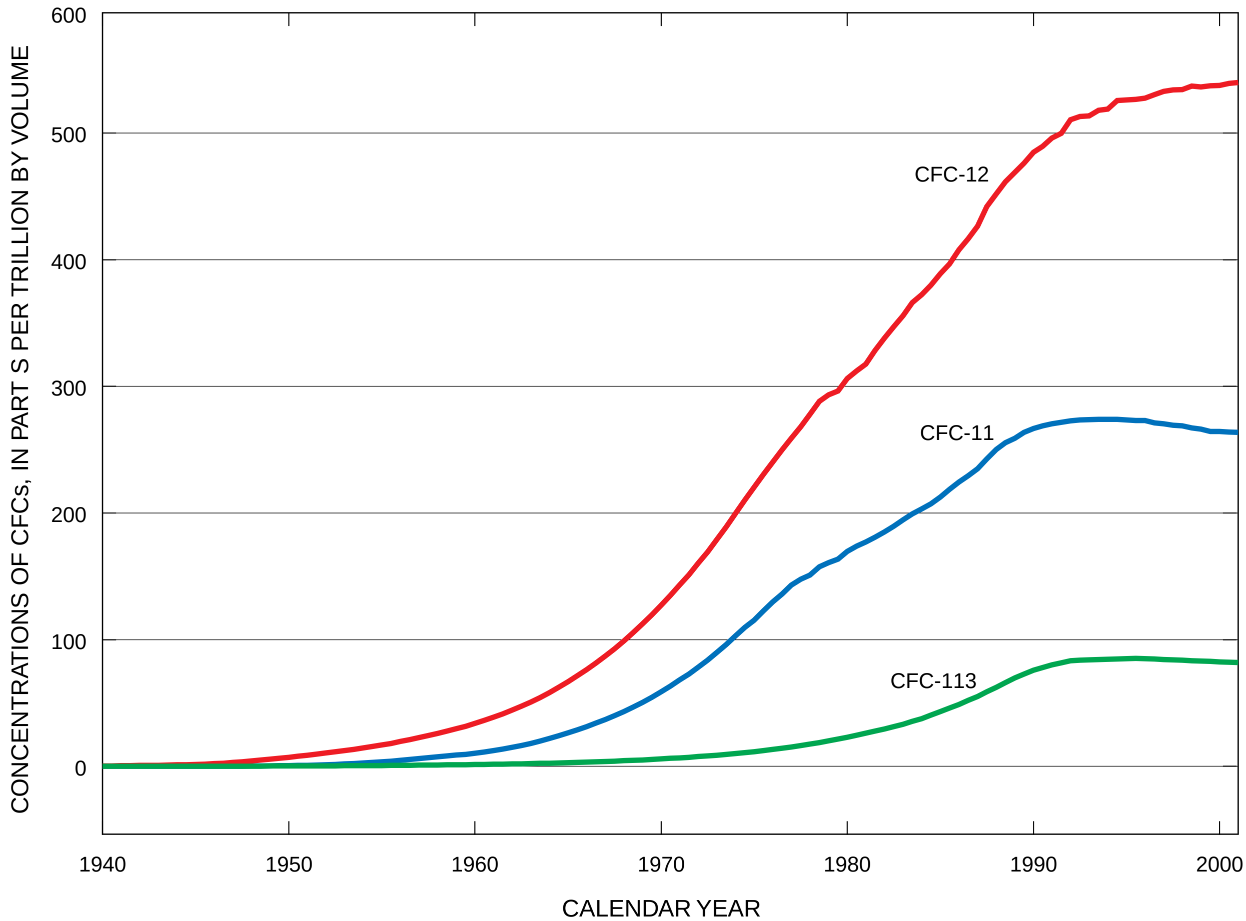


Figure 6. Concentrations of CFCs verses date.

Table 1. Low-level nutrients

Compound	Minimum reporting level (μg/L)
Nitrogen, ammonia	2.0
Nitrogen, nitrite	5.0
Total phosphorus, filtered water	6.0
Total phosphorus Nitrogen, ammonia, whole water	3.7
Nitrogen, nitrite	5.0
Phosphorus, phosphate, ortho	7.0

Table 2. Wastewater compounds

Compound	Use	Minimum reporting level (μg/L)
1,4-Dichlorobenzene	moth repellant, fumigant, deodorant	0.5
17-beta-Estradiol	estrogen replacement therapy and metabolite	5.0
1-Methylnaphthalene	nearly equal concentrations (2-5%) in gasoline/diesel/crude	0.5
2,6-Dimethylnaphthalene	indicator of diesel, kerosene, (not much in gasoline)	0.5
2-Methylnaphthalene	nearly equal concentrations (2-5%) in gasoline/diesel/crude	0.5
3-beta-Coprostanol	usually a carnivore fecal indicator	2.0
3-Methyl-1(H)-indole (skatol)	fragrance: odor in feces and coal tar	1.0
3-tert-Butyl-4-hydroxy anisole (BHA)	antioxidant, preservative	5.0
4-Cumylphenol	nonionic detergent metabolite	1.0
4-n-Octylphenol	nonionic detergent metabolite	1.0
4-tert-Octylphenol	nonionic detergent metabolite	1.0
5-Methyl-1H-benzotriazole	antioxidant in antifreeze, deicers	2.0
Acetophenone	fragrance: soap, detergent, tobacco; flavor: beverages	0.5
Acetyl hexamethyl tetrahydronaphthalene (AHTN)	fragrance: musk, widespread usage, persistent in ground water	0.5
Anthracene	wood preservative, in tar/diesel/crude (not gasoline)	0.5
Anthraquinone	Manuf dye/textiles; seed treatment, bird repellant	0.5
Benzo(a)pyrene	regulated PAH, used in cancer research	0.5
Benzophenone	fixative for perfumes and soaps	0.5
beta-Sitosterol	generally a plant sterol	2.0
beta-Stigmastanol	generally a plant sterol	2.0
Bisphenol	Manuf polycarbonate resins; antioxidant, FR	1.0
Bromacil	non-crop grass/brush control	0.5
Bromoform	byproduct of WW ozination , military	0.5

Table 2. Wastewater compounds

Compound	Use	Minimum reporting level (μg/L)
	uses/explosives	
Caffeine	medical: diuretic; highly mobile/biodegradable	0.5
Camphor	flavor, odorant, in ointments	0.5
Carbaryl	crop and garden uses, low environmental persistence	1.0
Carbazole	Manuf dyes, explosives, and lubricants, I	0.5
Chlorpyrifos	domestic pest/termite control; highly restricted	0.5
Cholesterol	often a fecal indicator, also a plant sterol	2.0
Cotinine	primary nicotine metabolite	1.0
Diazinon	insecticide non-agricultural uses, ants, flies, etc.	0.5
Dichlorvos	pet colors, flies; (breakdown of naled & trichlofon)	1.0
d-Limonene	antimicrobial, antiviral; fragrance in aerosols	0.5
Equilenin	prescription: hormone replacement therapy	5.0
Estrone	bioorganic hormone	5.0
Ethynyl estradiol	oral contraceptive	5.0
Fluoranthene	common in coal tar/asphalt (not gasoline/diesel)	0.5
Hexahydrohexamethyl Cyclopentabenzopyran (HHCB)	fragrance: musk; widespread usage, persistent in ground-water	0.5
Indole	pesticide inert, fragrance: coffee	0.5
Isoborneol	fragrance: perfumery, disinfectants	0.5
Isophorone	solvent for lacquers, plastics, oils, silicon, resins	0.5
Isopropylbenzene (cumene)	Manuf phenol/acetone; component of fuels/paint thinner	0.5
Isoquinoline	flavors and fragrances	0.5
Menthol	cigarettes, cough drops, liniment, mouthwash	0.5
Metalaxyl	soil pathogens, mildew, blight, golf turf	0.5
Methyl salicylate	liniment, food, beverage, UV-adsorbing lotions	0.5
Metolachlor	H (GUP), indicator of agricultural drainage	0.5
N,N'-diethyl-methyl-toluamide (DEET)	urban uses, mosquito control	0.5
Naphthalene	fumigant, moth repellent, about 10% of gasoline	0.5
Nonylphenol, diethoxy- (total)	nonionic detergent metabolite	5.0
Octylphenol, diethoxy	nonionic detergent metabolite	1.0
Octylphenol, monoethoxy	nonionic detergent metabolite	1.0
para-Cresol	wood preservative	1.0
para-Nonylphenol (total)	nonionic detergent metabolite	5.0

Table 2. Wastewater compounds

Compound	Use	Minimum reporting level (μg/L)
Pentachlorophenol	wood preservative, termite control	2.0
Phenanthrene	Manuf explosives; in tar/diesel/crude (not gasoline)	0.5
Phenol	disinfectant, manuf of several products, leach ate	0.5
Prometon	only non-crop areas, applied prior to blacktop	0.5
Pyrene	common in coal tar/asphalt (not gasoline/diesel)	0.5
Tetrachloroethylene	solvent, degreaser; veterinary: anthelminic	0.5
tri(2-Chloroethyl) phosphate	plasticizer and flame retardant	0.5
tri(Dichlorisopropyl)phosphate	flame retardant	0.5
Tributylphosphate	antifoaming agent and flame retardant	0.5
Triclosan	disinfectant, antimicrobial (concern: induced resistance)	1.0
Triethyl citrate (ethyl citrate)	cosmetics, pharmaceuticals, widely used	0.5
Triphenyl phosphate	plasticizer, resins, waxes, finishes, roofing paper, FR	0.5
Tri(2-Butoxyethyl) phosphate	flame retardant	0.5